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RESEARCH ARTICLE



Identification of elements exposed to flood hazard in a section of Trotuș River, Romania

Roxana Țîncu^a, José Luis Zêzere^b  and Gabriel Lazar^a

^a“Vasile Alecsandri” University of Bacău, Bacău, Romania; ^bInstitute of Geography and Spatial Planning – Universidade de Lisboa, Rua Branca Edmée Marques, Cidade Universitária, Lisbon, Portugal

ABSTRACT

The purpose of this study is to achieve flood hazard map in terms of limited data and identify the elements exposed to the hazard of floods produced by Trotuș River in section belonging to the commune of Ghimes-Făget, Romania. In order to identify the elements exposed to flood hazard, a first step was to determine the potential depth of water in flood conditions, using three bands of flooding for 10, 100 and 1000 years return period and the digital elevation model. In a second step, we elaborated the hazard map and hazard classification according to the Swiss method of hazard assessment, then the thematic layers with buildings and infrastructure were vectorized from orthophotoplan and inventoried in the field, the land use map was extracted from the Corine Land Cover 2012 data set. The maps of the exposed elements have been achieved based on thematic layers and hazard map. The results of this study provide information about the degree of flood hazard and about the elements exposed to hazard, which allows us to identify vulnerability and quantify the risk in a new study and also support the population and authorities to develop prevention and intervention measures in case of flood hazard.

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Flood; hazard; GIS; exposure; risk

1. Introduction

According to UNISDR (2004b) and ISO/IEC-31010 (2009), risk is generally defined as the probability of harmful consequences or losses (deaths, injuries, properties, means of production, interruption of economic activities or environmental impact) resulting from the interaction between hazards of the natural environment or human-induced hazards and the conditions of vulnerable elements. The concept of flood risk is formally defined by European and national standards, thus according to the 2007/60/EC Directive, means the combination of the probability of occurrence of floods

CONTACT Roxana Țîncu  roxanatincu@gmail.com

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and the potentially adverse effects on human health, the environment, cultural heritage and economic activity associated with the occurrence of a flood.

Flood risk is a product of flood hazard and the negative consequences of flooding and can be assessed by combining the following steps: hazard identification, hazard assessment, exposure assessment, vulnerability assessment and quantification of loss (Penning-Rowsell et al. 2005; Foudi and Osés-Eraso 2014). All three components of flood risk, namely hazard, exposure and vulnerability, are subject to changes in time. Floods are expected to become more frequent with a changing climate. Society's vulnerability and exposition to floods are also increasing due to increase exploitation of floodplains and the increasing complexity of technical infrastructure (Norén et al. 2016). This makes the assessment of present and future flood risk a particularly challenging task (Alfieri et al. 2015).

In the present study, we focus on the first three steps, which consist in examining floods with different probabilities of occurrence, achievement of hazard and identification and characterization of exposed elements.

Floods are part of the many natural hazards to which contemporary society is exposed, being a phenomenon responsible for human losses, economic and environmental problems in a global context (Philipp Schmidt-Thomé et al. 2006; EEA et al. 2008). Floods have been responsible for one-third of the economic losses resulting from natural disasters in Europe, being one of the most common type of natural dangerous events EEA et al. (2008).

Floods usually consist in the overflow of a river out of its natural bed and can be slow or fast. The flow resulting from significant rainfall lasting several days or weeks are considered slow and progressive, while flash floods occur due to extreme rainfall usually with a short duration, typically few hours. Flooding also includes sinking of land due to rising groundwater or overloaded drainage systems Julião et al. (2009). These extreme events may be caused by a variety of factors: winter or summer heavy rains, snow melting, broken dams, massive deforestation, or absence of drainage or flood protection works.

Regardless of their causes, floods can produce many damages, like serious impact on people health (drowning, injury, shock, etc.), severe power blackout, transportation and communication disruption, losses in agriculture and industry. Floods can also cause buildings evacuation because those houses that are penetrated by water cannot be inhabited. In addition, doors, walls and floors may deform or crack due to water infiltration. Also, the presence of mud and humidity can proliferate dangerous and harmful molds to human health.

The number and magnitude of events of extreme precipitation are increasing due to climate change (Dias 2013; Kharin et al. 2007; Santos and Miranda 2006; Vicente-Serrano et al. 2011), which increases the awareness of the dangers and damages associated. In the context of climate change, it is necessary to deepen the interdisciplinary scientific knowledge, to assess the risk and to create adaptation strategies in order to increase the resistance to extreme phenomena like floods (IPCC 2012, 2013; Min et al. 2011; Pall et al. 2011).

Although some floods are classified as technological hazards, namely those resulting from dam failure (UNISDR 2009), most floods are part of the category of natural

hazards. According to the dictionary of terms developed under the aegis of UNESCO and the International Decade for Natural Disaster Reduction (IDNDR) Secretariat in 1992, a hazard is a threatening event (Grecu 2009).

UNISDR (2004a,b) defines ‘danger/hazard’ as ‘a potentially harmful physical event or human activity that can cause life losses or injuries, material damage, social and economic disruption or environmental degradation’. Hazard assessment is aimed at characterizing the flood pattern by means of relevant metrics (e.g. flow velocity, water depth, flood extension) coming from hydraulic models (deterministic or probabilistic), according to different scenarios to be investigated (baseline or alternative) (Ronco et al. 2014). In other words, once the hazard type has been identified, the magnitude is identified and the probability of occurrence of the event is calculated. The magnitude and probability are essential for obtaining the hazard map and for identifying the elements exposed to flood hazard.

Exposure can be defined as people, assets and values located in floodplains (IPCC 2012; Kron 2005). Exposure is a major component of the disaster risk and refers to which is affected by natural disasters, such as people and property (ADRC 2009). Exposure describes the number of people and the value of structures and activities that will experience hazards and may be adversely impacted by them (Blanchard 2005; Davidson and Lambert 2001).

Exposure is the presence of people, goods or other potentially subject to be damaged in areas where floods are occurring (Commission 2010; UNISDR 2009) and can be quantified by the number or value of the elements found in flood affected areas Merz et al. (2007). Without exposure there is no risk, thus, very fragile elements (e.g. old buildings) that are not exposed to flooding will always have a zero flood risk (Bruijn et al. 2009). Here, exposure is understood as the number of persons and/or other elements at risk that may be affected by a particular flood event. In an uninhabited area, human exposure is zero. No matter how many floods will affect an uninhabited area the human exposure, and therefore the risk of human loss, remains zero (Thywissen 2006).

Also, people and buildings are exposed only if they do not have sufficient structural or private measures against the flood (e.g. walls, gravity dampers). In other words, a building is not exposed when it is surrounded by a solid stone wall, because this protective element will keep all the water out. Social conditions also influence the susceptibility to suffer flood damage, by the knowledge about hazard and age of people affected, for example. The means by which people or organizations use available resources and abilities to face adverse consequences that could lead to a disaster are defined as the coping capacity (UNISDR 2004a). In the social context, exposure is influenced by population dynamics, ability to manage the environment, inability to get active because of economic and social inequalities (Villagrán de León 2006). So, in the context of risk-hazard, the exposure term proved to represent the inside of the risk and the external of vulnerability (Costa and Kropp 2013). When the exposure is a risk component, addresses people and artefacts exposed at high risk (Crichton 1999; UNDP 2004).

Regardless of how it is perceived, the exposure is a component without which the risk assessment would not be possible. The ultimate result of the exposure assessment

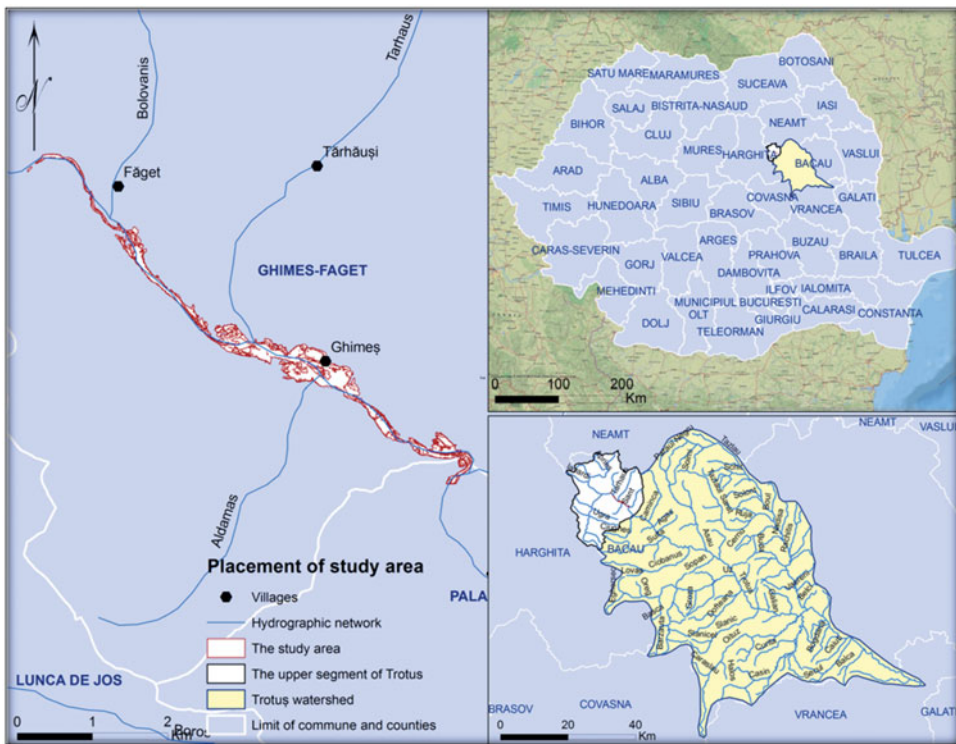


Figure 1. The geographical position of Siret Basin and study area.

is the map of the exposed elements. According to Schanze et al. (2006), the exposure assessment consists of a cartographic representation of the elements exposed to floods and their classification and may include diverse topics as the environment, heritage, infrastructure, economic or other relevant activities for risk analysis.

The aim of this paper is to achieved the flood hazard map on the basis of which we identify and analyze the elements exposed to the hazard of flooding in the upper segment of Troțuș River Făget and Ghimeș villages, associated with a rural community, as a first step in the process of assessing vulnerabilities, calculating damages and quantifying flood risk in the study area.

2. Study Area

Troțuș River is a Romanian river, having the origin in Ciuc Mountains and a length of 162 km. Oriented from NW to SE, it crosses the mountain peaks of Ciuc, Tarcaului and Gosman, the east side of the Nemira Mountains, Oituz and Casin, Berzunti Mountains, Carpathian Tazlău – Casin Depression, and the Sub-Carpathian massif of Ousor flowing into the Siret River near Adjud (Figure 1).

The Troțuș Valley is occupied by a significant number of rural communities, so in its upper and middle sector from the border between Bacău and Harghita counties and to Comanesti town there are five communes (Ghimeș-Faget, Palanca,

Brusturoasa, Agăș and Asău), summing approximately 21,000 inhabitants according to 2011 census (INS 2011).

The study area is situated between the upper and the middle part of the Trotuș River, respectively, Făgetul de Sus, Făget, and Ghimes villages, belonging to Ghimes – Faget commune, from the north-western part of Bacău county, Romania. From the 5094 people living in the whole commune, according to 2011 census (INS 2011), the study area includes approximately 3000 persons. The other around 2000 persons are living in other three villages and they are also exposed to hazard, as they are frequently affected by flash floods that occur in other rivers, Bolovăniș and Tărhăuși.

Flash floods occurred along the Trotuș River frequently with different degrees of intensity. Historical flood events were recorded in 1670, 1673, 1675, 1724, 1774, 1775, 1850, 1851, 1860, 1864, 1897, 1912 and 1914 (Vives and Peyraud 2009). More recently, high floods were recorded in 1960, 1970, 1975, 1991, 2004, 2005, 2007, 2010 and 2016 (Vives and Peyraud 2009).

These flood events generated significant negative effects on the community, according to the synthesis report elaborated by ISU Bacău and ABAS (2005, 2010). During the flood event in 2005 70 houses, 50 household annexes and 35 ha of agricultural land were flooded. In addition, 3 bridges, 5.5 km of communal road were disrupted by the flood. More recently, the flood event registered in the period 26 June 2010 to 28 June 2010 generated damage to 22 houses and 64 household annexes. The disruption along roads affected 7.090 km of communal road, 1.177 km of rural road and 0.090 km of the national road (DN 12 A) (ABAS 2005, 2010).

According to the Siret Basin Water Administration (Administrația Bazinală de Apă Siret, in Romanian) (ABAS), flash floods occurring in the study area are difficult to forecast because of the large surface with high slopes in the upper section of the valley and the relatively short travel time of the water to the lower section. In this area floods often cause significant damage, because, over time along the quite narrow valley of Trotuș River houses and human activities, agriculture, economic activities and infrastructure have been developed (ABAS 2005, 2010). In addition, the impact of flood events has been increased by the presence of households actually on the riverbank of the river and the presence of two main traffic routes, a national road, and a railway, linking two parts of the country across mountains.

3. Data and Methods

In order to identify the elements exposed to the flood hazard in Ghimes-Faget area the following database were used: the digital elevation model (DEM) obtained by LIDAR measurements (provided by ABAS) with 5 m spatial resolution and vertical accuracy below 1 m. The Digital Surface Model originally provided by the LIDAR system was transformed into the DEM that is related with bare-Earth raster grid referenced to a vertical datum (ABAS). The vectorized road and railway networks, river network, buildings and bands of flooding with return period of 10, 100 and 1000 years, were provided by the Project Plan for the prevention, protection and mitigation of floods in the basin of the Siret River (RNWA 2012). The data were processed using the ArcMap10 software.

A first step was the water depth calculation for the study area, based on the DEM with 5 m spatial resolution and flooding bands with a return period of 10, 100 and 1000 years, respectively. The flooding bands were used like mask to extract one DEM corresponding for each return period 10, 100 and 100 years. From each DEM thus obtained fringe values of fringe pixel were extracted, from upstream to downstream. For each set of values corresponding to the three return periods interpolations were made using the 3-D Analyst Tools, having as a final result three DEM's, one for each of the flooded areas associated with return periods of 10, 100 and 1000 years. From each obtained DEM the original DEM was subtracted and the difference represents the depth of water. This procedure is a solution in limited data conditions, in our case the lack of data and software necessary for the achievement of a hydro-dynamic model.

Given the fact that we focused on return periods, it is appropriate to define this expression and also present the formulas by which these return periods were calculated. Thus, the return period is the probability of repetition of a flood with the determination of the magnitude and is generally defined as the average number of years between occurrences of two successive events with an identical magnitude (Andrade et al. 2006). Return periods, reflecting the probability of occurrence are related to the probability of exceedance obtained from Equation (1), where p is the probability of exceedance and T is time, usually set in years.

$$p = \frac{1}{T} \quad (1)$$

The probability of exceedance is directly related to the probability of an event of a certain magnitude to be exceeded. The probability of non-exceedance is obtained using Equation (2), where p' correspond to the probability of non-exceedance and T is time in years (Dias et al. 2014; Bründl and Margreth 2015).

$$p' = 1 - \frac{1}{T} \quad (2)$$

The elaboration of the hazard map and hazard classification was made using the Swiss method of hazard assessment, one of the most well established and widely accepted guideline for assessing natural hazards (Raetzo et al. 2002). This method is based on a matrix diagram which defines three levels of hazard (low, medium and high) according to the probability and intensity/magnitude, presented in Figure 2.

Originally, the probability is given by the frequency of the expected floods (the probability of occurrence of flood events), and the magnitude is given by the kinetic energy (Lateltin et al. 2005). In our work, the maps representing the depth of the water during floods of different magnitudes, with return periods of 10, 100 and 1000 years were combined, obtaining the overall magnitude of the flood. In order to obtain the probability, the three flooding bands associated to each of the considered return period 10, 100 and 1000 years return periods was converted to raster format. Thus the three raster previously obtained were combined using the Cell Statistical function from Local – Spatial Analyst tools.

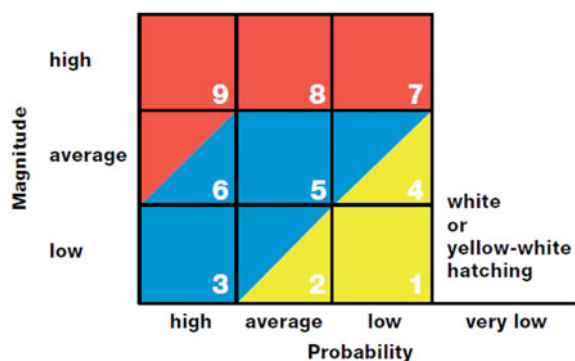


Figure 2. Magnitude – probability diagram (hazard level diagram), red – high; blue – medium; yellow – low, adapted from Loat and Petrascheck (2008).

The two raster maps representing the probability of occurrence of floods and flood magnitude, were combined in a final raster, representing the hazard map with three classes defined following diagram in Figure 2. This procedure, raster's combining was performed using the Spatial Analyst tools – Local – Cell Statistical.

The elements exposed to flood hazard (buildings, road and railway networks) were vectorized from the orthophoto plan obtained from aerial photogrammetry in 2010, produced and provided by National Cadastru Agency and Imobiliar Advertising – Cadastre and Imobiliar Advertising Office. The land use was derived the Corine Land Cover 2012. Additional information on buildings was obtained by field work: buildings were divided in two categories, living houses and household annexes. In terms of construction material, two categories of materials were identified: wood and aerated concrete. The predominant buildings (60%) are constructed of wood followed by those built of aerated concrete (40%).

By overlapping the layers representing all infrastructure elements of interest with the hazard map, the degree of exposure of each element was calculated. In this study, we chose to analyze the buildings exposed taking in account the water level inside the building during the flood occurrence.

Considering the fact that in the GIS the water level of a flood is stored in a raster type grid structure and the buildings are represented by polygons, it was necessary to execute some procedures in order to allocate the values to network polygons (Dias et al. 2014). For example, as a rule, a building polygon overlay with the raster representing the water depth will correspond to several pixels on the grid. In these cases, these pixels will be selected to calculate the mean value of the water level inside the building, and the mean value is then assigned to the polygon representing the building.

In the case of this study, in order to allocate the values to network polygons, the buildings polygon format was converted to raster, assigning to cells value 5, and then the pixels corresponding of buildings were assigned as NoData; this raster was multiplied with the raster representing the total water depth (magnitude), thus obtaining a raster in which the pixels corresponding to the buildings have no value. With the buffer tool, a buffer of 5 m was created for all buildings, needed in the next operation. Using raster resulting from the multiplication and buffer, the average water

Table 1. Classification criteria for probability and magnitude raster maps.

No.crt.	Type of raster maps	Criteria of Swiss method	Our data	Degree
1.	Magnitude	$h < 0.5$ m	0–0.5 m	Low magnitude
		$0.5 \text{ m} > h < 2$ m	0.5–2 m	Medium magnitude
		$h > 2$ m	2–3.77 m	High magnitude
2.	Probability	>300 years – 40 to 15%	1000 years	Low probability
		30–100 years – 82 to 40%	100 years	Medium probability
		1–30 years – 100 to 82%	10 years	High probability

depth was calculated and associate to the corresponding buildings, assumed as the water level inside the buildings.

The difference between the water level and the topography provided the water depth. The buildings are located at the topographic level and we assume no obstacle exist for the entering of water inside the building. Assuming this, the water level in a building was calculated as the average water depth registered in those pixels that cover the building.

4. Results

4.1. Flood magnitude and probability

The three raster maps representing the water depth for each return period of 10, 100 and 1000 years were reclassified according to the magnitude and probability classes of Swiss method for hazard assessment (presented in Table 1) and are showed in Figures 3–5. The zoomed areas in each map allow for viewing some interest areas with lower visibility. The low and medium magnitude are dominant in the three maps corresponding to the three considered return periods, while the high magnitude occurs in reduced areas, but is important as value, reaching a maximum of 5.76 m in the case of the 1000 years return period, and values over 3 m for all cases.

The overall magnitude of floods expressed as water depth was obtained by combining the three rasters representing the water depth corresponding to the return periods 10, 100 and 1000 years, and is showed in Figure 6.

The probability is shown in Figure 7. It decreases along the river, being higher in the first section, in the upper zone and lower in the final section of the study area. Comparing the two maps representing magnitude and probability of floods (Figures 6 and 7) we conclude that in the first section of the river, floods have a higher probability and higher magnitude, whereas in the downstream section, the probability is lower and the magnitude remains high in some sectors.

The *high magnitude* is symbolized with red colour and means that the water depth is high enough for the buildings. That means that the buildings are seriously damaged and even destroyed, persons living in these buildings as well as animals are exposed to risk; the roads and the railway are unusable, the bridges are seriously affected, even destroyed. Local erosion and deposition of boulders and debris also occur (Loat and Petrascheck 2008). In our case the high magnitude has values between 2 and 3.77 m which means that buildings become completely flooded, given that in the study area all buildings have only one level and mostly they are constructed of wood. Also, infrastructures are greatly affected due to the fact that most roads except DN 12

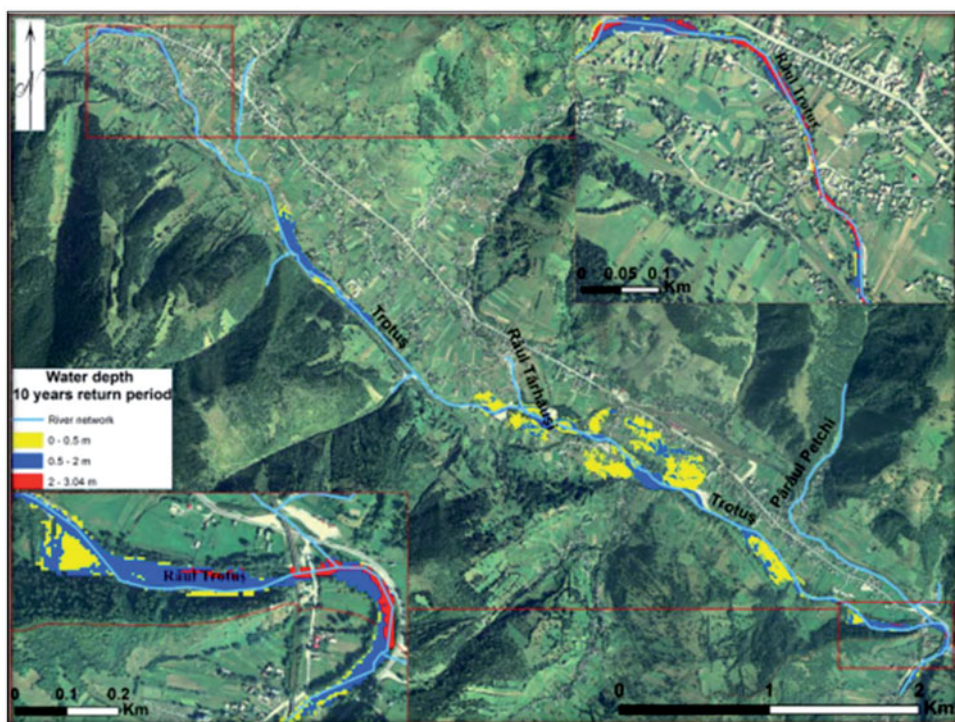


Figure 3. Water depth for 10 years return period.

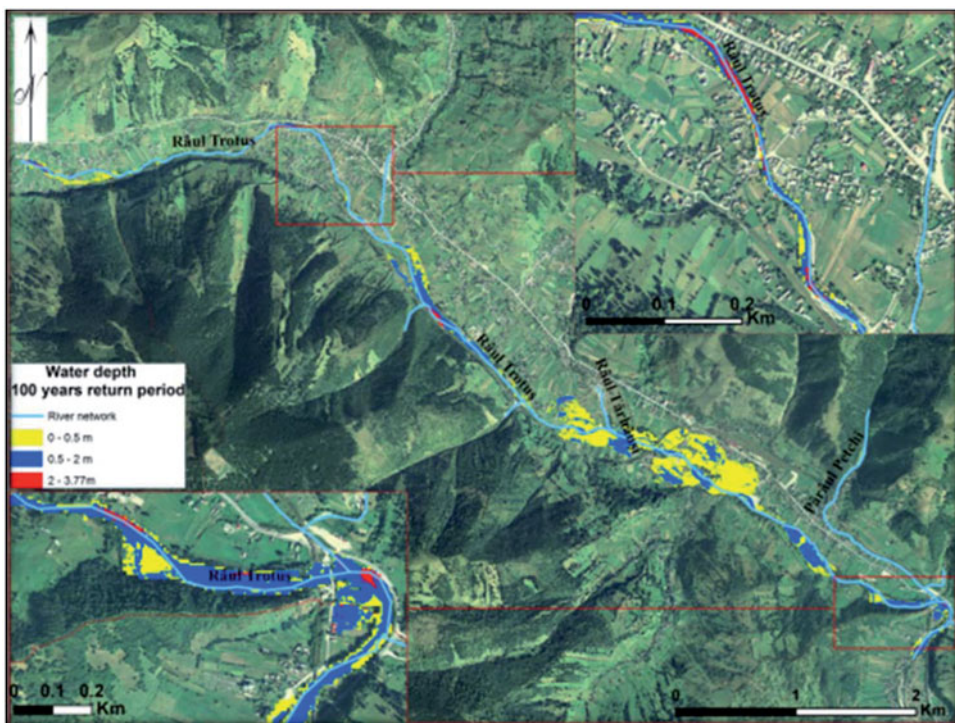


Figure 4. Water depth for 100 years return period.

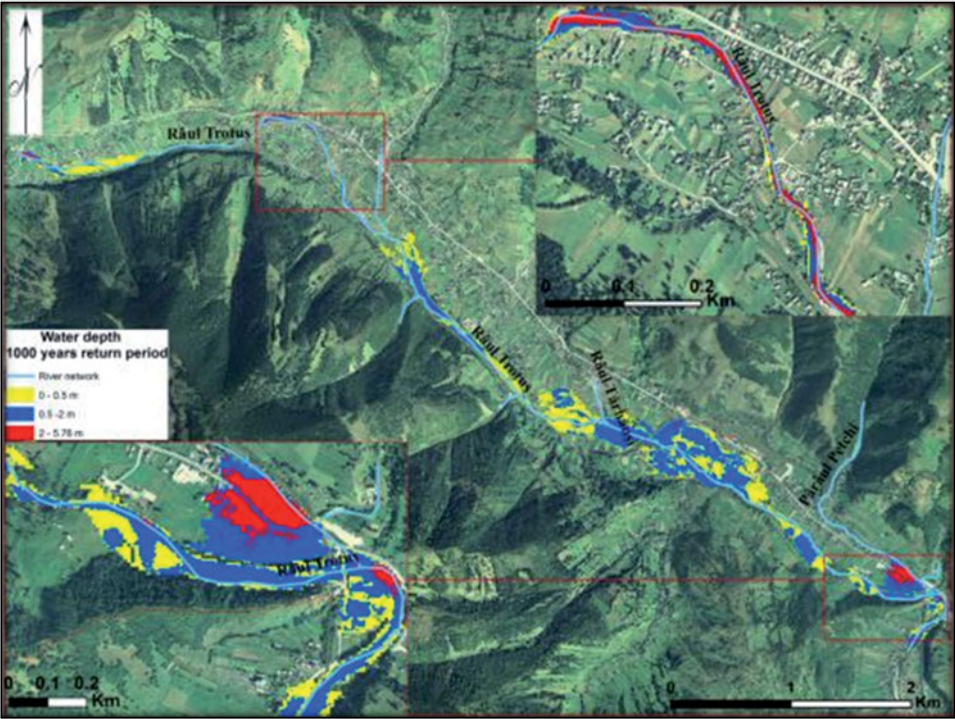


Figure 5. Water depth for 1000 years return period.

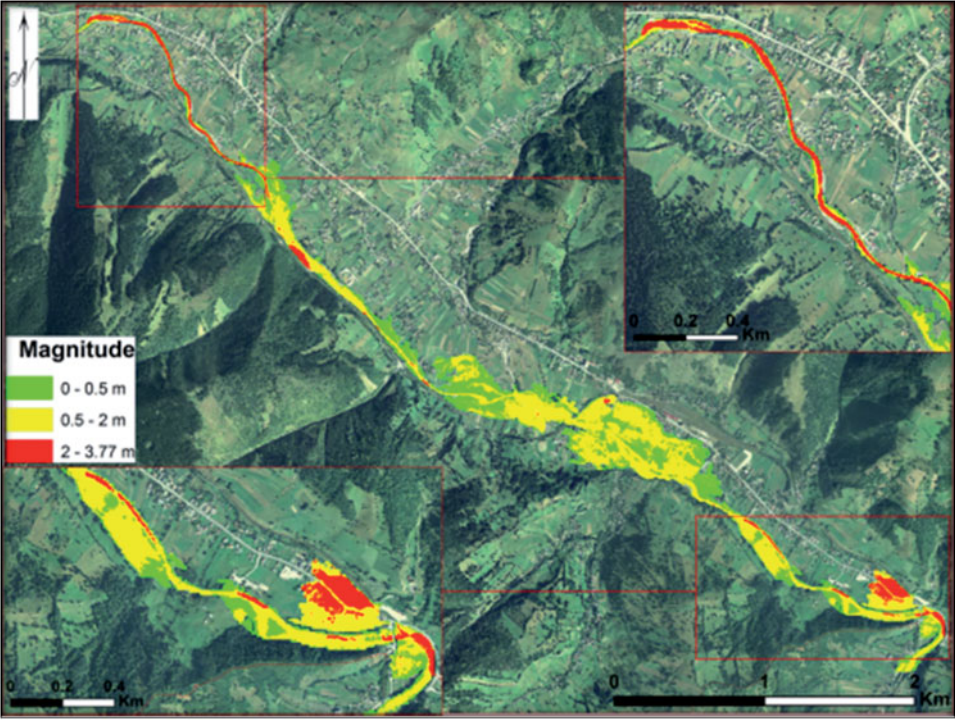


Figure 6. Overall magnitude of floods expressed in terms of water depth.

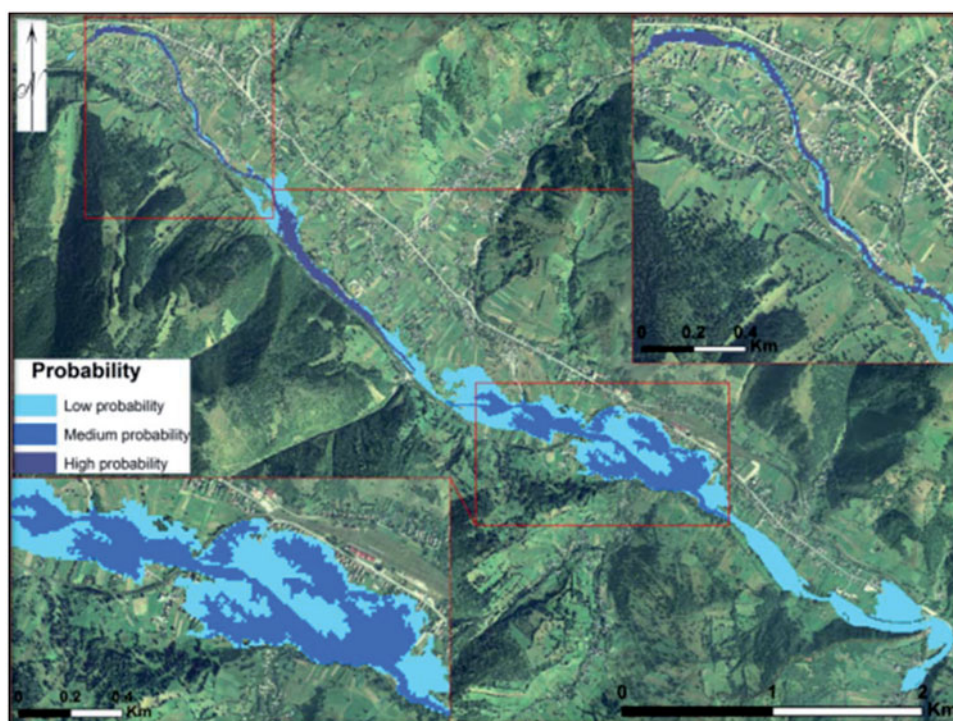


Figure 7. Probability of flood.

A are cobbled (ballast) or from the ground and culverts are poorly consolidated. The *medium magnitude* is symbolized with yellow colour. The water penetrates into the buildings, cellars, and ponds for water pumps, windows and fences can break. Transport of alluvia, erosion, and sediment deposition can occur. Persons and animals outdoors and in vehicles are exposed to risk. The values corresponding to this class of hazard are between 0.5 and 2 m and have low impact on buildings and infrastructure, the danger is practically halved compared to the previous class. The *low magnitude* is symbolized with green colour. This class includes values between 0 and 0.5 m, which means that the danger is rather low for buildings. Water that threatens to enter in buildings can be deviated by relatively simple means, however, cellars are exposed to risk. Normally, there is no risk to persons and animals (Loat and Petrascheck 2008). Agricultural crops can be affected by the addition of alluviums and not asphalted roads can be eroded due to the flowing water.

In the study area the most vulnerable exposed elements are the buildings, most of them are houses built of wood and household annexes, made of low-quality materials, very few are built of autoclaved cellular concrete blocks. When the water comes inside, all categories of buildings are significantly affected because water infiltrates the walls, floor and also can affected the carpentry. However, in conditions of dynamic floods, the buildings built of wood and the household annexes are the most affected, because of the weakness of their structure, while autoclaved cellular concrete blocks buildings are more resistant.

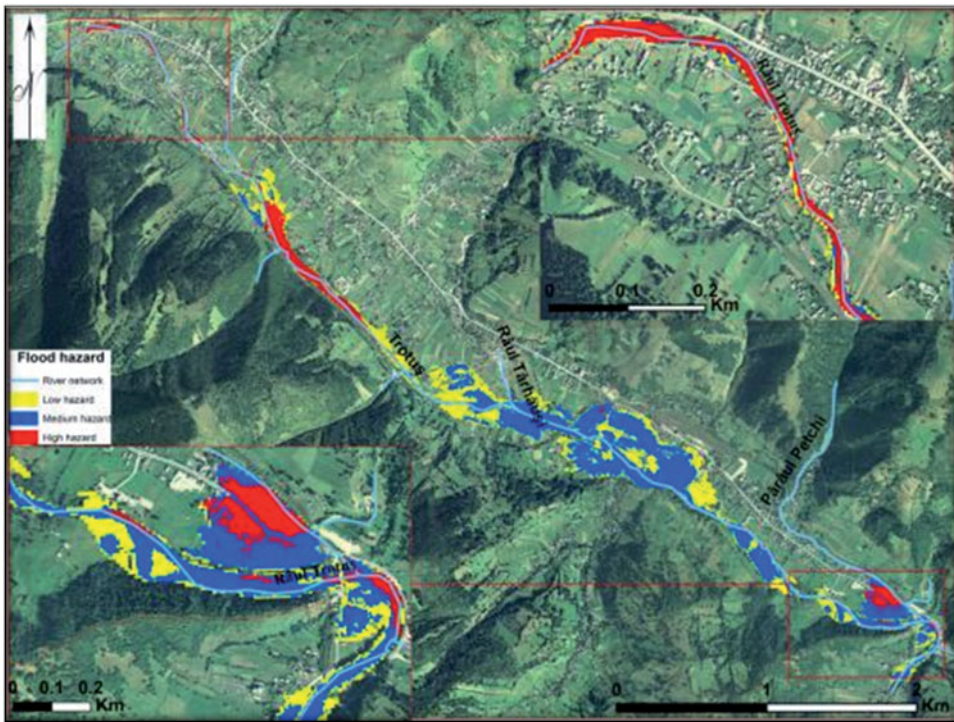


Figure 8. Flood hazard.

4.2. Hazard map

The combination of the two raster maps representing the probability of occurrence of floods and the flood magnitude presented in Figures 6 and 7 using the classification scheme summarized in Figure 2 generated the hazard map, presented in Figure 8.

According to the Swiss method, in the high hazard zone, symbolized with red colour, sudden destruction of buildings can occur and all living things are in danger both inside and the outside of buildings. Normally, the red zone is a prohibited area for regular human activities.

The medium hazard zone, symbolized with blue colour, is a zone where the persons are exposed to the risk of injury outdoors, inside the building the risk being lower. Deteriorations of the buildings are expected, but not a sudden collapse, if constructions are adapted to the present conditions. Blue area is a restricted area for regular human activities.

The low hazard zone, symbolized with yellow colour, is the area where the persons are less exposed. It can record a slight deterioration of buildings, obstacles must be anticipated, substantial damage to buildings are still possible. Humans are exposed to a low risk of injury. Mainly, the yellow zone is a warning area (Lateltin et al. 2005; Loat and Petrascheck 2008).

The analysis of the hazard map shows that even if the dominant colours are blue and yellow, the red areas are still very important. Part of these areas is used for a residential destination indicating the lack of any hazard evaluation from the

Table 2. Exposed elements occurring at each level of hazard.

Type of exposed element	The degree of hazard			Total
	Low	Medium	High	
Residential road	0.921 km	0.559 km	0.04 km	1.52 km
Unclassified	0.194 km	0.185 km	0.145 km	0.524 km
Alley	0.221 km	0.298 km	–	0.519 km
Primary road	0.011 km	0.271 km	–	0.282 km
Railway	0.096 km	0.242 km	0.015 km	0.353 km
Bridge	1	3	4	Eight bridges
Building	60	120	20	200 buildings

municipality. In fact, an important part of the commune can be categorized as prohibited or restricted area, according to the concepts used in this study.

4.3. Exposure of the infrastructure

The exposure of the infrastructure was estimated by overlapping the hazard map to the layers representing roads, railways, bridges and buildings. The railways, bridges and buildings were not divided into different categories, and the roads were classified as the primary road, residential roads, alleys and unclassified roads. For buildings and bridges, the exposure was determined by identifying the number of exposed elements, while for the categories of roads and railway was calculated the length in each hazard type. To calculate the length of the roads and railway, the raster representing the hazard map was converted into vector format and then was calculated the length of each category of road intersecting with each type of hazard. The obtained results are summarized in Table 2.

The exposure of the different type of roads and bridges is mapped in Figure 9.

A total 17 road segments equating 2.845 km were identified as being exposed to flood hazard, from which 7 residential equating 1.52 km, 5 unclassified equating 0.524 km, 5 alleys equating 0.519 km and two sections of the national road, DN 12 A equating 0.282 km. The exposure of the primary road (national road DN 12A), Figure 9 was identified in two sections: medium hazard at 93 km and low hazard at 91 km.

A total of eight bridges were identified as exposed to flood hazard in the area of study, four of them are exposed in the high hazard zone, three bridges are exposed in the medium hazard zone and one bridge in the low hazard zone, Figure 9.

The railway has a length of 10 km in the area subject of study and from the map presented in Figure 10 it can be observed that is exposed to flood hazard in several sections totalizing 0.353 km.

4.4. Exposure of buildings

A number of 200 buildings are exposed, representing houses and animal shelters. Most of the buildings (60%) are located in the zone of medium hazard and a small part of buildings (10%) are located in the zone of high hazard.

Taking in account the water level in buildings, three classes of hazard were established, first from 0 to 0.5 m, second from 0.5 to 1.5 m and third from 1.5 to 2.47 m.

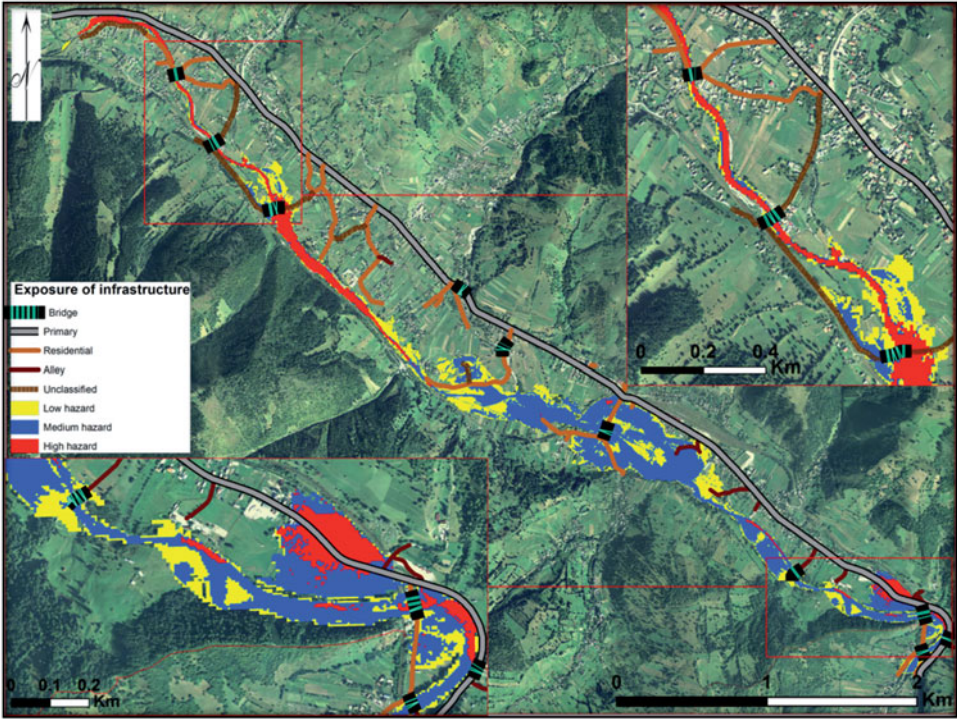


Figure 9. Exposure of different type of roads and bridges to flood hazard.

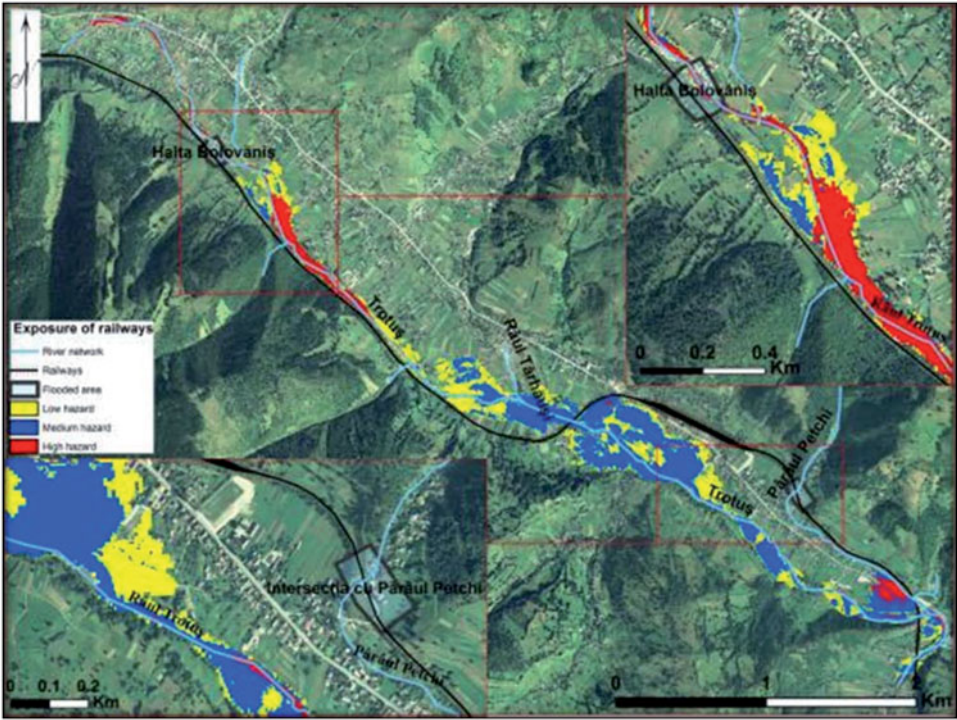


Figure 10. Exposure of railway and the flooded areas in the past.

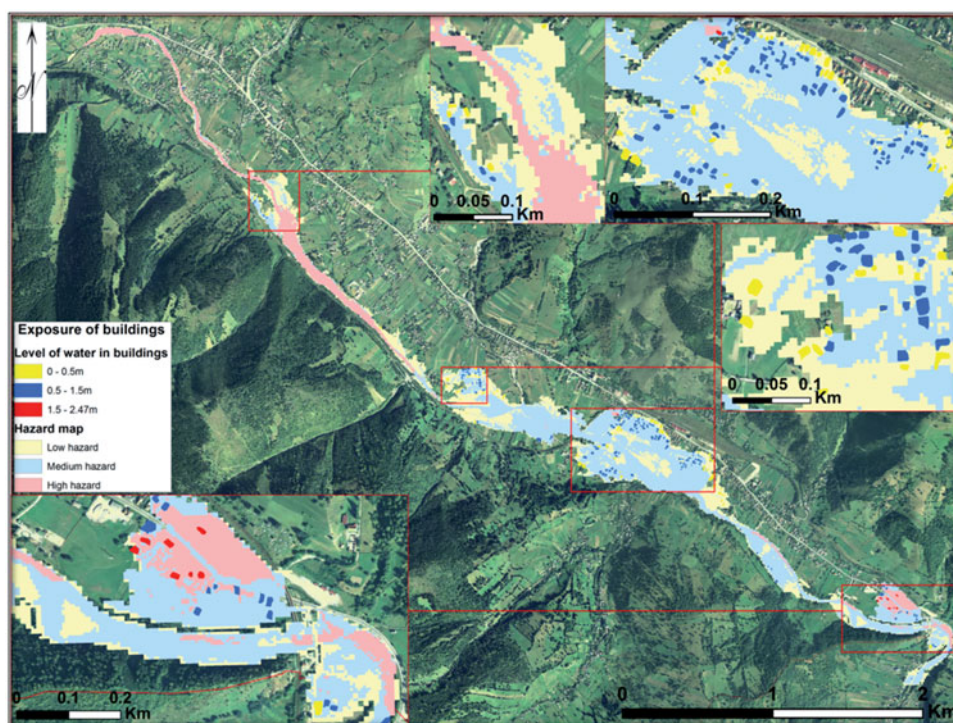


Figure 11. Exposure of buildings to flood hazard depending on the water level inside.

This classification was made starting from the statement of Vilier et al. (2014) that consider a damage equal to 50% of the maximum damage if the water depth is 1 m. Moreover, the *average deterioration function for residential buildings specific to Europe*, developed by (Huizinga et al. 2017) was also taken into account. According to this, buildings with a water level up to 0.5 m will not suffer significant damage, whereas buildings with a level of water between 0.5 and 1.5 m may suffer damage up to 50%. Finally, building damage will be over 50% for water level over 1.5 m. Following these features, the first class of water level (0–0.5 m) was assigned a low hazard, whereas the medium hazard and high hazard were assigned for the next water level classes (0.5–1.5 m and >1.5 m, respectively).

The obtained results regarding the water level in the flooded buildings are shown in Figure 11. Approximately 60% of buildings have a level of water between 0.5 and 1.5 m, that means are exposed in the area of medium hazard, 30% of buildings have a level of water between 0 and 0.5 m corresponding to the low hazard, and 10% of buildings have a level of water between 1.5 and 2.47 m corresponding to the high hazard.

The buildings identified as being exposed to flood hazard belong to two categories of buildings. In approximately equal proportions, they are residential houses with a single-level and household annexes used for animal husbandry. As we mentioned in section 3, about 60% of these buildings are built of wood and 40% are built of autoclaved cellular concrete blocks, the high percentage of wood houses contributes to increasing vulnerability to flood risks.

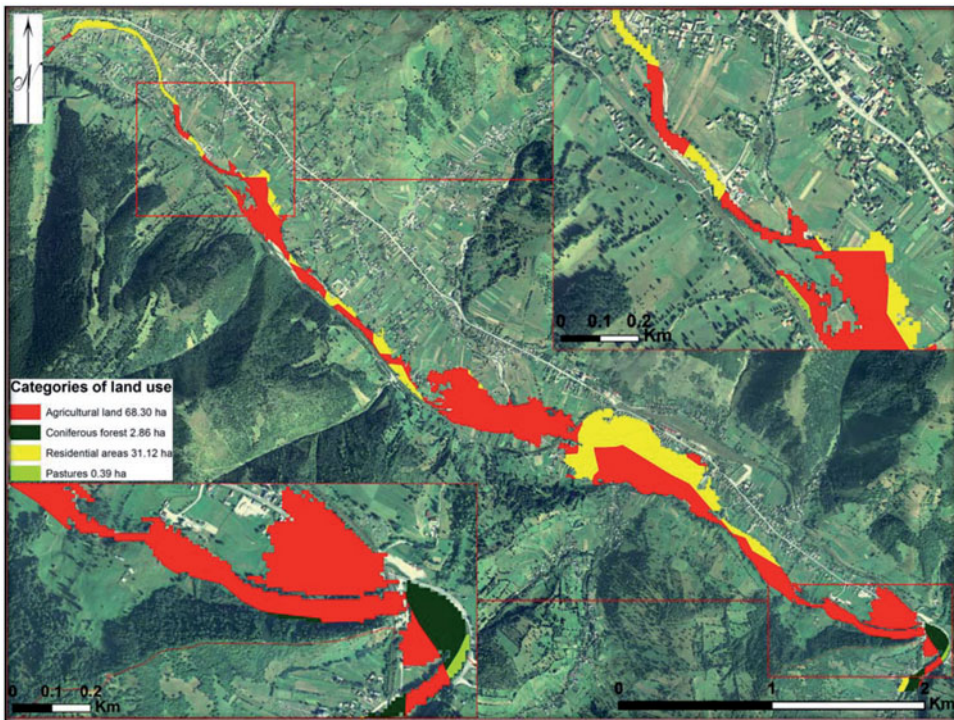


Figure 12. The main categories of land susceptible to be flooded.

4.5. Exposure of land use

In the study area approximately 105 ha land are exposed to flood hazard, according to the CLC 2012 data set this land is used as follows: 68.30 ha agricultural land, 2.86 ha coniferous forest, 31.12 ha residential areas and 0.39 ha pastures. This information is mapped in Figure 12. The inhabitants use agricultural land mostly for the cultivation of fodder plants (lucerne, clover) for animals and on smaller areas for cultivation potato because it is an area with somewhat elevated altitudes, improper for cereal crops.

5. Discussion

In this paper, the goal was the achievement of a hazard map and the identification of exposed elements to flood hazard. The obtained hazard map highlights areas that are affected by or vulnerable to floods. The identification of different hazard zones allows for the evaluation of assets or items at risk, meaning everything that could be exposed to hazards: buildings, agricultural land, economy, infrastructure and persons.

The hazard map indicates areas susceptible to flooding and includes three hazard classes: high hazard, found in the upper part and a section of the lower course, medium hazard that includes the middle and lower part of the study area and low hazard that include several parts of the total area. The area exposed to a high hazard is not very large but is associated with high values of the water depth, which can have a catastrophic effect, especially on buildings.

A number of 200 exposed buildings were identified, representing single-level houses and household annexes constructed mainly of wood or autoclaved cellular concrete blocks. These buildings are inhabited and used at a rate of 97% and we can also say, following discussions with locals that about 60% of them have been flooded in the past, some even three times.

The most important result regarding the exposure of the roads is related to the national road DN 12A, an important communication route between two Romanian regions, across the mountains. The road is exposed to a high flood hazard in two points, a subject of concern because an eventual destruction would cause significant disruption both to the local community and to many companies.

In addition to this national road, there are also exposed segments from other secondary roads classified as residential, unclassified and alleys; these roads are used to connect the main national road to the inhabited areas and agricultural land. From these, 14 are exposed to a high or medium hazard, indicating the problems of the zone.

In the study area, 8 bridges were identified. They are of small size, some of them being constructed from wood and iron, but the eventual destruction of them will jeopardize the access to houses as well as to the main traffic routes.

The railway is another component of the infrastructure exposed to flood hazard in various sections. Past flood events have affected the railway in two points. During the flood occurred in 2010, the flow of the Trotuş River caused strong erosion on the right bank which caused a vertical rupture at a distance of 2.5 m from the track line. The event led to the stopping of the railway traffic during 2 d, cancelling 15 trains.

6. Conclusions

The evaluation of the exposure to the flood hazard was made using GIS tools, maps and field work. The final hazard map contains three different hazard classes, medium and high hazard being dominant. Approximately 1500 people living along the Trotuş River, as well as their households, are exposed to the flood hazard.

Moreover, two main traffic arteries exposed to flood hazard in different points were identified in the study area: National Road 12A, respectively, the railway line, both linking two parts of the country. Other infrastructure parts identified as exposed to flood hazard were 200 buildings, secondary roads, and bridges.

From the information collected concerning the historical flooding events, we can state that all the identified elements were affected by past floods in different proportions, according to the synthesis reports provided by (ABAS 2005, 2010). For example, as a result of the floods in 2005 at the level of Ghimes-Faget commune, about 70 houses and 50 household annexes were flooded; in terms of infrastructure three bridges and 5.5 km of communal road were affected, as well as 35 ha of agricultural land (ABAS 2005).

The elements exposed are significant in relation to the surface of the study area but also in terms of the importance of the elements, this determines us to continue the study by quantifying the value of the damages in future work. Further, we intend

to identify the degree of vulnerability in this area and to evaluate risk due to flooding.

This study is an important step to assess flood risk in this area, providing the necessary information to continue with vulnerability assessment and risk quantification.

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ORCID

José Luis Zêzere  <http://orcid.org/0000-0002-3953-673X>

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